1982

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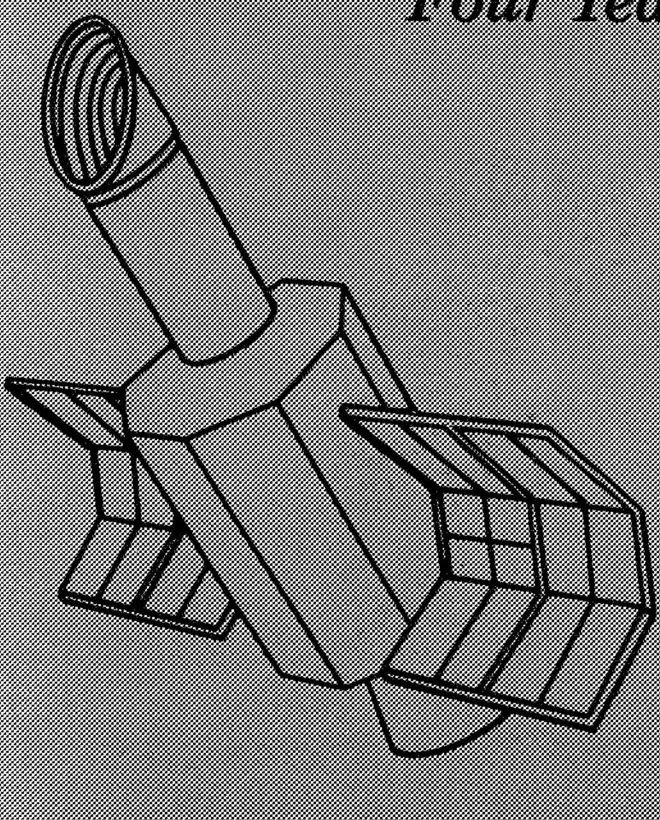
Recommended Citation

Michalitsianos, A.G., Kafatos, M. (1982). UV emission from the M1 supergiant TV Gem. In Y. Kondo, J.M. Mead, & R.D. Chapman (Eds.), *Advances in Ultraviolet Astronomy: Four Years of IUE Research*. Proceedings of a Symposium held at NASA Goddard Space Flight Center, Greenbelt, Maryland, March 30-April 1, 1982 (pp. 263-267).

NASA Conference Publication 2238

Advances in Ultraviolet Astronomy:

Four Years of IUE Research



Proceedings of a symposium held at
NASA Goddard Space Flight Center
Greenbelt, Maryland
March 30 - April 1, 1982

NASA

UV EMISSION FROM THE M1 SUPERGIANT TV GEM

by

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ABSTRACT

Low and high dispersion ultraviolet spectra were obtained of the M1 supergiant TV Gem with IUE. Previous IUE observations of this late type supergiant revealed unexpected UV continuum emission, perhaps arising from an early B companion. Low resolution spectra obtained approximately one year apart suggest that the strong Si III in combination perhaps with O I at wavelengths $\sim \lambda 1300$ A varies considerably with time. Large variation in the column density is required to explain these changes. Sporadic mass expulsion with mass loss rates $dM/dt \sim 10^{-5}\ M_{\odot}\ yr^{-1}$ from the M supergiant could lead to a dense circumstellar wind near the hot early companion, and thus could account for these observed variations in equivalent width. The high resolution spectrum in the $\lambda 2000$ to 3200 A wavelength range is characterized by narrow absorption lines primarily due to Fe II, Mn II and Mg II (h and k), which are skewed in profile with an extended red wing. We tentatively attribute this profile structure to interstellar absorption and an intervening differentially moving cloud in the direction of Gem OB1, of which TV Gem is a known association member.

INTRODUCTION

The late type supergiant TV Gem = HD 42475 (M1 Iab) that was found to exhibit strong UV continuum (Michalitsianos, Kafatos and Hobbs 1980) has been re-investigated with IUE. A comparison of low dispersion spectra obtained in the SWP wavelength range approximately one year later suggests that a few of the strong absorption features attributed to S II?, Si III and C II vary with time. Previously we have applied an interstellar correction to the UV continuum of E(B-V)=0.4, consistent with early estimates for reddening obtained in the visual by Crawford et al. (1955) and Eggen (1967). However, this extinction correction did not fully correct for the strong $\lambda 2200$ A feature which is clearly present in our LWR ($\lambda 2000$ to 3200 A) spectra. Rather, more recent estimates of E(B-V)=0.65 (A_V = 2.16) of Humphreys (1978) agrees more closely with the strength of the $\lambda 2200$ A feature observed with IUE. We adopt an E(B-V)=0.65 and show the de-reddened spectra for different observing epochs in Figure 1.

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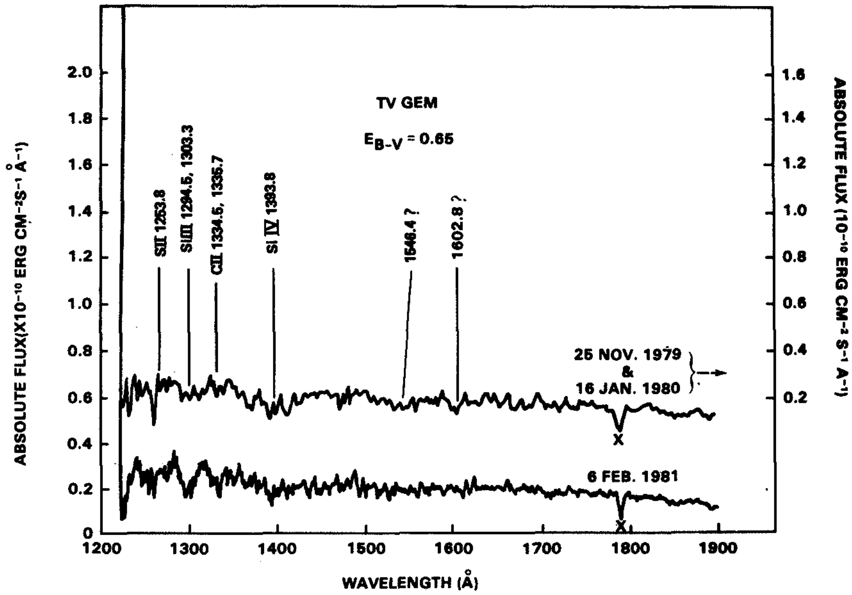

Figure 1

The continuum distribution in the SWP (λ1200 - 2000 A) wavelength range corrected with E(B-V)=0.65 is best approximated by an early B type companion. The presence of Si III, Si IV and possibly S II is consistent with absorption features that characterize UV spectra of early type stars, although variations in the absorption strengths of these features suggests somewhat more complicated processes are present. This follows because considerable variations in column densities are required to produce the observed changes. Possibly, sporadic mass ejection in the wind of the M supergiant results in large variations in column density along the line-of-sight with $\rho \sim 10^{13}$ cm^{-3}. Such high values in wind density are unusual, but are required to explain the changes in equivalent widths for Si III and/or O I.

Additionally, high resolution spectra obtained in the LWR wavelength range (λ2000 - 3200 A) reveal narrow absorption lines which are attributed to interstellar Mn II, Fe II and Mg II (h and k). The strong h and k lines of Mg II ($\lambda\lambda$2795, 2802 A) centered at their rest wavelengths appear skewed in profile in the sense of an extended red wing. Skewed profiles of interstellar Mg II also characterize the line profiles of Mn II, but are not as clearly evident in Fe II. This skewness is possibly explained by an intervening differentially moving cloud ($\sim$+20 km s^{-1}) in the direction of Gem OB1, of which TV Gem is a known association member, and which is estimated to be $\sim$1400 pc (Crawford et al. 1955). Our observing program and analysis of data follows. The apparent magnitude corrected for extinction is m_V = 6.58.

OBSERVING PROGRAM

In Figure 1 the SWP spectra for 25 November 1979 and 16 January 1980 (10 minute exposures each) have been averaged together in order to reduce the relative noise in the data. Inspection of the individual spectra for each of these dates indicates that the absorption features present did not change. A 40-minute SWP spectrum on 6 Feb. 1981, however, clearly indicates significant increases in absorption strength at λλ1256, 1300 and 1334 A. Sufficient signal was not obtained that absorption features could be discerned with an 8-hour SWP exposure.

Table 1

Ion	Multiplet	λIUE(A)	λLaboratory(A)
S II?	1	1259.8	1253.8
Si III	4	1295.5	1294.5-1303.3(6 lines)
O I?	2	1301.0	1302.2
C II	1	1333.0	1334.5,1335.7
Si IV	1	1393.4	1393.8
C IV?	1	1546.4?	1548.2,1550.7
Fe II?		1435.6	1434.9
Fe II?	193	1473.4	1473.8
Fe II?	38	1708.6	1708.6
Fe II?	397	1844.4	1844.6
Fe II?	65	1853.8	1852.4

A number of ions indicated with ? in Table1 are tentatively shown. In Table 2 absorption lines detected with the high dispersion LWR camera are given, that are corrected for Earth and satellite motion (+22.5 km s^{-1})

In Figure 2 the Mg II (h&k) lines are shown at their measured wavelengths, which is very close to the rest wavelengths. Two unidentified lines are present, where the feature at λ2798.9 A should not be confused with the subordinate line Mg II mul. (3) λ2797.9 A. Its associated line at λ2790.8 A is not present. The unidentified feature at λ2800.5 A appears real and may be a blend of high order multiplets of Mn II (6), (7), (20), (21) and (22). Figure 3 shows the strongest Mn II (1) line which exhibits similar structure as Mg II (h & k).

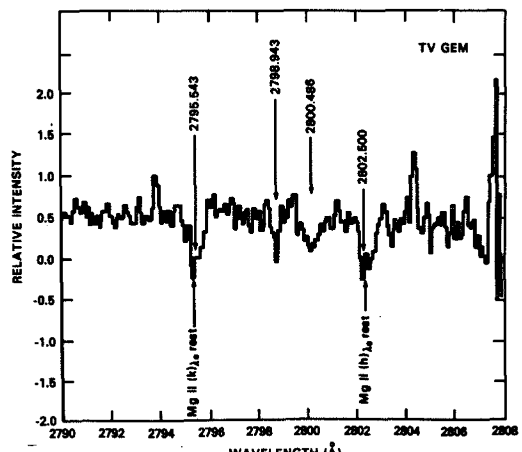

Figure 2

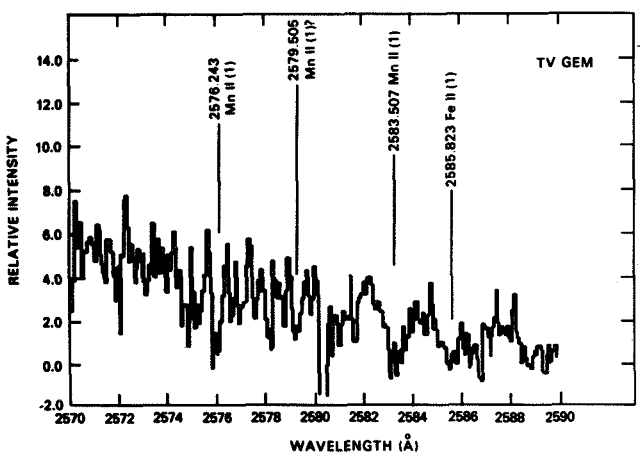

Figure 3

DISCUSSION

The average UV continuum flux observed throughout the entire sensitivity range of IUE is $F_\lambda \sim 2 \times 10^{-11}$ erg cm^{-2} s^{-1} A^{-1}, after applying an interstellar extinction correction E(B-V)=0.65 to the observations. The relative apparent visual magnitudes between primary and secondary stars can be obtained by extrapolating the corrected UV continuum to the visual. The bolometric magnitude is derived that corresponds to a distance d $\sim$ 1400 pc for which $M_{bol} \sim -3.0$. This value of M_{bol} lies well within the range of a B5 to B0 star (Allen 1973) if the secondary is a main sequence type companion. For a B5 star, M_V = -1.1 and $m_V \sim 11.8$, and correspondingly for a B0 star, M_V = -4.1 and $m_V \sim 8.8$. The relative magnitude differences between primary

Table 2

High Dispersion LWR Spectrum

Ion	Multiplet	λ IUE (A)	λ Laboratory (A)
Fe II	3	2343.5	2343.495
Fe II	2	2373.8	2373.733
Fe II	2	2382.2	2382.034
Mn II		2492.9	2492.716
Mn II	1	2576.2	2576.107
Fe II		2579.5	2579.406
Mn II	1	2583.5	2583.538
Fe II	1	2585.8	2585.876
Mn II	1	2593.8	2593.731
?		2599.3	
Mn II	1	2605.7	2605.697
Mn II		2617.3	2616.934
Mn II	19	2618.5	2618.145
Fe I		2738.0	2732.832
Mn I		2738.9	2738.861
Mn II		2740.4	2740.161
Mg II (k)	1	2795.5	2795.523
?		2798.9	
?		2800.5	
Mg II (h)	1	2802.5	2802.697
Fe II	255	2826.3	2826.024
Fe I		2827.9	2827.670
Mn II	2865	2865.7	2865.600

and secondary, respectively are $\Delta m_V \sim 5.2$ and 2.2, a sufficiently large difference that the secondary can remain undetected in the visual. As found by Michalitsianos et al. (1980) the companion dominates the integrated light at wavelengths $\lambda < 3600$ A.

The Si III $^3P^o$-^3P multiplet has an equivalent width of $\sim$6100 mA in Feb. 1981 (for all 6 lines), and if compared to our previous low resolution spectra has attainted this width over a period 1 year. Using the "square root" portion of the curve of growth curve we find column densities $n(\text{Si III}, {}^3P^o)L \sim 3.5 \times 10^{23}$ cm^{-2}, which corresponds to atomic parameters for this multiplet of Weise, Smith and Glennon (1966), where $n(\text{Si III}, {}^3P^o)$ is the number density of Si III ions in $^3P^o$ (lower level of $^3P^o$-^3P) Because $^3P^o$ levels are metastable to the ^1S level, the population of the $^3P^o$ levels builds up collisions from the ground state. Writing the equilibrium equation for the three lowest levels for Si III, namely ^1S (ground state), $^3P^o$ (6.6 eV above ground) and the $^7P^o$ (10.3 eV above ground), we find that the relative abundance of the $^3P^o$ levels is

$$N(^3P^o) \sim \omega_1\, e^{-E_{21}/kT} / [\omega_1 (\tfrac{\omega_2}{\omega_1}\, e^{-E_{21}/kT} + 1) + \omega_1 e^{-E_{32}/kT}] \,, \quad (1)$$

where "1", "2" and "3" refer to the ^1S, $^3P^o$ and $^1P^o$ states, respectively. It follows that if $T \sim 17{,}000$K appropriate for a B star (B3), then $N(^3P^o) \sim 0.1$, $N(^1S) \sim 0.9$ and $N(^1P^o) \ll N(^3P^o)$, $N(^1S)$. It follows from equation (1) that the lower limit to column hydrogen density (assuming cosmic abundances) is $nL \sim 4 \times 10^{24}$ cm^{-2}, where n is the hydrogen density and L the pathlength through the region.

If we use the wind equation $\dot{M} = 4\pi R^2 m_H v$ and use $R \sim L/2$ appropriate for a B3 star ($R \sim 5.2 R_\odot$) and $v \sim 700$ km s^{-1} (B3 star of $7 M_\odot$), we find that $\dot{M} \gtrsim 1.6 \times 10^{-5}$ $M_\odot$ yr^{-1}. We note that the mean laboratory wavelength for transition λ1298.9 A is $\sim$2 A redward of the observed feature, indicating possibly mass motion $\sim$450 km s^{-1}. Had we used the wind equation appropriate to a red supergiant, i.e. $v \sim 100$ km s^{-1} and $R \sim 600 R_\odot$ we would find (assuming a $T \sim 10^4$K shell around the supergiant) that $\dot{M} \gtrsim 6 \times 10^{-3}$ $M_\odot$ yr^{-1}, which would be reflected in in changes of zero volt lines such as O I λ1302.2 A. If most of the changes in equivalent width around λ1300 A is attributed to Si III, the absorbing region would have to be located near the B star. At present it is not clear as to which of the two stars this large value of $\dot{M} \sim 10^{-5}\ M_{\odot}\ yr^{-1}$ actually refers. Unfortunately, the present low dispersion spectra cannot provide unambiguous information regarding the velocity profiles of these observed features. Mass loss rates $\sim 10^{-5}\ M_{\odot}\ yr^{-1}$ are substantially large compared to typical values associated with either early B stars (cf. Cassinelli 1979), or late type supergiants (cf. Goldberg 1979). If, however, material is expelled from the cool M supergiant in sporadic bursts, the presence of dense material in the direction of the B companion could provide spectroscopic indications of the total mass loss from the supergiant, in a manner similar to that found for α Sco by van der Hucht et al.,(1980) who suggest a large extended dusty region for this star. TV Gem is likely another example of such systems, where UV continuum arising from the early companion enables us to obtain additional spectroscopic methods of examining mass loss from late type supergiants. Further UV-satellite observations could resolve this question if high dispersion spectra were feasible in the λ1200-2000 A wavelength range. Perhaps Space Telescope will provide the clues?

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